Software Engineering Institute

SoS Navigator 2.0: A Context-Based Approach to System-of-Systems Challenges

The SEI SoS Navigator Team

June 2008 (revised September 2008)

TECHNICAL NOTE
CMU/SEI-2008-TN-001

Carnegie Mellon

Software Engineering Institute

SoS Navigator 2.0: A Context-Based Approach to System-of-Systems Challenges

Philip Boxer
David Carney
Suzanne Garcia
Lisa Brownsword
William Anderson
Patrick Kirwan
Dennis Smith
John Morley

Carnegie Mellon

Table of Contents

List of Figures

List of Tables

Acknowledgements

This technical note reflects an evolution of thinking about various issues in complex systems of systems. The Carnegie Mellon® Software Engineering Institute (SEI) team working on SoS Navigator has taken some different directions than those anticipated when the first technical note on SoS Navigator was published. A significant part of that shift comes from the addition of Philip Boxer, formerly of BRL Ltd., to the technical staff of the SEI and to the SoS Navigator team. All of us on the team would like to particularly acknowledge the role that Phil's thinking and mentoring have had on SoS Navigator. We also would like to thank him for the generous way he has shared his prior works with us.

A change in intellectual direction often means challenges in incorporating the new ideas into the current frame of reference, especially when some of those ideas challenge conventional wisdom. The team would like to thank our SEI colleagues, particularly Patricia Oberndorf, Jeannine Siviy, Dennis Smith, Jim Smith, Soumya Simanta, and Lutz Wrage—all of whom read drafts of this technical note and helped us frame these ideas in ways that are accessible.

Abstract

Organizations struggle with many problems in complex systems of systems for which solutions are not codified or even conceived, such as a mutual understanding of "common" terms and concepts across participating enterprises and the lack of a global view by any single system-of-systems participant. System and software purchasers and suppliers need a different set of approaches and techniques than are typically in use today to satisfy user demands that reflect turbulent operational environments. Beyond purchasers and engineers, all participants in a complex, systems-of-systems environment need a different set of perspectives and expectations about user demands than those typical in product-centered engineering. The SoS Navigator approach provides leaders participating in complex systems of systems with (1) novel insights into critical aspects of the demand and supply sides of their situation and (2) criteria on which to decide whether their systems-of-systems context requires the adoption and sustainment of a different business model than ones that are typical today. This technical note introduces the fundamental concepts, processes, and techniques of the evolving SoS Navigator approach. It also summarizes case studies that illustrate the use of SoS Navigator processes and tools in healthcare, military, and civilian government systems-of-systems contexts.

1 Background

Over the past decade, there has been a significant shift in the way in which information technology (IT) systems are built and deployed. The development of individual, standalone systems has decreased, and IT software systems now tend to be designed, developed, and fielded with the expectation that an individual system will be a part of a larger network of systems, commonly termed a system of systems [Miller 2001, Singh 2007, Beaudouin-Lafon 1999].

This shift toward systems of systems has also occurred in domains other than IT. For instance, the U. S. Department of Defense (DoD) is now moving rapidly toward network-centric operations, in which individual weapons systems are related elements in a global web of systems. In the finance, manufacturing, healthcare, and service industries, network-based computing is proliferating as is the service-oriented architecture (SOA) approach, a particular architectural style defined by the OASIS Reference Model as "…a paradigm for organizing and utilizing distributed capabilities that may be under the control of different ownership domains" [OASIS 2006].

The tasks of designing and developing software in such a context are considerably different from those of designing and developing software for a standalone system. Many of the software engineering disciplines—such as requirements engineering, software architecture, testing, maintenance, and support—are significantly changed from their traditional norms. The challenges posed by such systems present equally unfamiliar problems to the user community, since the elements of the entire system are often unknown and undergo independent (and often conflicting) evolution. More users are also becoming "user programmers" in that they perform the final adaptations needed to make the software system usable for their current purpose [Forrester 2006].

Both users and developers are struggling with unfamiliar problems for which solutions are not yet codified or, in some cases, are not even conceived. A very different set of techniques is needed for both systems and software engineering; even more, a very different set of perspectives and expectations from the user community must become institutionalized.

Consequently, the Carnegie Mellon® Software Engineering Institute (SEI) is engaged in an initiative whose focus is systems of systems. The ISIS (Integration of Software-Intensive Systems) Initiative was chartered to address the interoperability needs of current and future government and industry organizations as they face unprecedented issues in migrating to network-centric operations and systems of systems.

A major element in the ISIS work has been the ongoing development of a set of practice-based technologies, unified by a common set of core concepts, which we term the SoS Navigator[SM] approach. The initial ideas about this approach, published in 2006, started to frame the problem and highlighted some exemplar techniques and a nominal process for approaching appropriate solutions. This technical note builds on, refines, and in some cases moves beyond the ideas in the original SoS Navigator, based on what we have learned through research and customer engagements.

The SoS Navigator technologies as of this writing include analysis methods, modeling tools, and processes. The fundamental concepts of SoS Navigator 2.0 target difficult-to-perceive aspects of managing, engineering, and operating in a systems-of-systems context that is primarily characterized by a need for distributed collaboration in an environment of highly variable demand. Although there are certainly less complex contexts in which systems of systems are developed, operated, and evolved, we believe that finding and testing techniques and processes that will work in this complex situation will ultimately provide useful tools and techniques for addressing simpler situations as well.

As organizations move toward greater development, evolution, and use of such systems, the SoS Navigator approach can provide leaders of those organizations with insight into the balance needed among the many participants and tensions in a complex system-of-systems undertaking: system creators, providers, vendors, customers, and users; and, most importantly, the context in which complex systems are expected to perform.[1] The concept of system provider accounts for acquisition agents and system integrators. In some situations, they may also be considered creators.

We chose the term *navigator* intentionally. In the traditional sense of the word, a navigator is the individual whose task is to plan, record, and direct the movement of a ship or airplane from one place to another. Different navigational techniques have evolved in different cultures, but all of those techniques involve *locating one's position compared to known locations or patterns*. It is this notion of finding one's position in an unfamiliar space that suggested the term *navigator* for our work: all of the modeling and analysis tools and methods we use have the common aim of bringing awareness to individuals and organizations about their "location" or "bearing," in the virtual sense, as they move into the unfamiliar and complex world of systems of systems.

Just as a ship's navigator requires a large array of tools (a traditional set of navigator's equipment, according to Wikipedia, could include dozens of items [Wikimedia 2008]), the SoS Navigator approach relies on a rich set of diverse technologies rooted in a set of related concepts, each of which has some specific focus on a particular issue or challenge brought about by a systems-of-systems perspective.

In Section 2 of this technical note, we describe the SoS Navigator approach in terms of its evolving fundamental concepts. Section 2 is aimed at readers interested in the "why" of SoS Navigator. In Section 3, we describe the essential techniques and processes of this approach that have proved useful to date; it is meant for readers more interested in "what is" SoS Navigator. In Section 4, we briefly describe some of the uses of the SoS Navigator approach in real-world contexts. It addresses readers interested in "where has it been used." In Section 5, we briefly discuss our plans for future work, addressing "where are we going from here." It is important to note that subsequent technical reports and notes will provide additional detail on all of these topics, which are presented here in only a general introductory manner.

---

[1]   Where no ambiguity is likely, we shall from this point shorten "complex systems of systems" to the simpler term *complex system*s or just *system*s and use the longer phrase only when necessary.

2 Fundamental Concepts that Support SoS Navigator

The SoS Navigator approach is intended to provide insight into the balance needed among the many participants and tensions in a complex system-of-systems undertaking. We define a complex system of systems as *a collaboration among autonomous systems that occurs in relation to some business purpose or mission objective and within a changing and unpredictable context.* Some of these systems are technical (e.g., software and hardware), others are organizational (i.e., involving humans). Within SoS Navigator we are therefore dealing with socio-technical systems as a whole.

We are not the first researchers to address socio-technical issues of complex systems. The study of systems and the way humans and groups of humans interact with and are a part of them goes back decades, at least as far as the work of the Tavistock Institute of Human Relations [Trist and Murray 1990, 1993] and of the management cybernetics movement of the 1950s [Beer 1959]. The growth of study in these topics has led to many different branches and a rich source of ideas, including systems theory, systems thinking, cybernetics, complex adaptive systems, non-linear systems, and systemics. Although we have been influenced by several of these heritages, our work draws particularly on ideas from Maturana and Varela [Maturana and Varela 1980] related to the nature of autonomous behavior, the work of Kolb [Kolb 1984] in terms of experiential learning, and the work of Rosen [Rosen 1991] in terms of the relational approach to understanding anticipative systems. Our perspective is concerned with the nature of dynamic living systems, rather than with mechanistic or purely structure-determined ones.[2]

By recognizing that systems of systems are socio-technical collaborations [Hirschhorn 1984], we focus on what is normally thought of as the customer of the system of systems rather than on the supplier of an individual constituent system. The customer of the systems of systems is, in fact, an enterprise that uses systems to provide services to its own customers—the service users. Table 1 shows high-level definitions for the main roles we discuss for a complex system-of-systems collaboration.

Table 1: Definition of Key Roles

System Supplier	The entity that creates and offers some system element for use by others
Customer Enterprise	The enterprise that uses systems to provide services to service users
Service User	Those who express demand for and use the services of the customer enterprise

The example of an electronic medical record service (EMRS) in one hospital, viewed as a single customer enterprise, illustrates this view of complex systems of systems. For this EMRS, the complex socio-technical system of systems encompasses the supplier of the EMR software, the deployment organization within the hospital that will use the EMR software to provide a service (i.e., customized access to medical records), and the IT group in the hospital that will host and sustain it. The clinicians who will use it and probably others (including patients) become the ser-

---

[2] A future technical note will explore the roots of our ideas and how they have led to our current thinking. For this overview report, we allude to these few sources to help orient readers who are interested in systems science connections.

vice users. Note that there can be many suppliers, both outside and inside the hospital. Table 2 places the roles in the EMRS example in the context of our high-level definitions. If the EMRS were to be shared in a Regional Healthcare Information Organization (RHIO) with several participating hospitals, clinics, and pharmacies, the number of suppliers and customers—and the complexity of understanding the system of systems—would grow.

Table 2: Key Roles in a Simple Context

Role	High-Level Definition	Definition Applied to EMR Example
System Supplier	The entity that creates and offers some system element for use by others	The organization(s) that develop(s) the EMR software
Customer Enterprise	The enterprise that <u>uses</u> systems to provide services to service users	The EMRS deployment organization in the hospital; the IT organization in the hospital
Service User	Those who express demand for and use the services of the customer enterprise	The clinicians (and potentially the patients)

In a DoD context, the system supplier is likely to be a contractor, while the customer enterprise is a logistics organization within one of the military services, and the service users would be the military units operating in the field who are using the IT and other services provided by the logistics organization.

When we shift our focus on complex systems of systems from system supplier to customer enterprise, we must also change many of our traditional ways of thinking about engineering and management [Fisher 2007]. Making this shift introduces a number of related challenges, such as

- unknown internal and external suppliers of component systems within systems of systems
- lack of a global view of the systems of systems by any one of these suppliers
- system-of-systems composite capabilities unable to keep up with service users' needs
- unanticipated behaviors emerging between component systems
- latent incompatibilities between component systems
- synchronization challenges across the systems of systems
- different meaning attached to common terminology across the systems of systems
- fusing of data and information across the systems of systems

Underlying these kinds of system-of-systems challenges are (1) difficulties in seeing the whole system (e.g., lack of a global view) and (2) effectively communicating relevant information (e.g., different understanding of terminology).

The SoS Navigator approach offers tools to address both kinds of challenge through improving awareness of the many tensions that have to be balanced in a systems-of-systems situation and understanding the kinds of communication that are required across diverse participants in systems of systems. The focus of this approach is the relationship between suppliers and customers in the context of continually changing requirements (demand) from the users of the services provided by the customer enterprise. The SoS Navigator approach explores that relationship through several interrelated concepts, which are addressed in the sections that follow:

1. the customer enterprise and the purchaser-provider boundary
2. supply, demand, and organizational context
3. the gap between supply and demand

4. the importance of context-of-use
5. the double challenge of governance and demand
6. the implications of decentralized governance
7. the requirement for agility

2.1 THE FOUNDATION: THE SOS ENTERPRISE AND THE PURCHASER-PROVIDER BOUNDARY

A concept that figures prominently in almost all discussions of systems is that of an *enterprise*. This term has many definitions; the following are representative:

> *An enterprise (or "company") is comprised of all the establishments that operate under the ownership or control of a single organization. An enterprise may be a business, service, or membership organization; consist of one or several establishments; and operate at one or several locations. . .* [USCB 2002].

> *[An enterprise] is a collection of organizations and people formed to create and deliver products to customers* [Oracle 2007].

> *[An enterprise is] a system of business endeavor within a particular business environment . . .[it includes] an enterprise architecture (EA), which is a design for the arrangement and interoperation of business components ([e.g.], policies, operations, infrastructure, information) that together make up the enterprise's means of operation* [BSI 2007].

In general, the concept refers to a collection of organizational entities, persons, processes, and systems that together are engaged in some common purpose under a single source of control (by control we primarily mean decision-making authority). But the overall concept can be recursive, which sometimes makes its use ambiguous. For instance, the DoD will often refer to itself as *an* enterprise. But within the DoD, the Air Force also refers to itself as *an* enterprise, and within the Air Force, many of its constituent commands also refer to themselves as enterprises. In each case, what is being referred to is actually a *locus of control*. This distinction is important, because when we place a boundary around an enterprise, we do so by reference to what it *controls* not to what it "owns."

Consequently, systems suppliers—commercial software contractors, for instance—that are seen as being outside the customer enterprise in ownership terms fall within the boundaries of a customer enterprise when they come under its control as sub-contractors.[3]

An important boundary to establish between a customer enterprise and the users of its services is between the user as purchaser of both products and associated services and the enterprise as the provider across which services (that include the products) are provided.[4] The providers satisfy one or (typically) more demands from the purchaser side of the boundary. Figure 1 illustrates this traditional way of thinking about the purchaser-provider boundary, with the purchaser being the customer enterprise, and the provider being the systems supplier.

---

3   In order to distinguish it from the definition of boundary in terms of ownership, it is useful to refer to a boundary established by control as a *perimeter*.

4   We use *purchaser-provider* rather than *customer-supplier* boundary. A customer-supplier boundary carries the connotation of the situation where a service is being supplied to a customer from a supplier outside the enterprise. In complex systems of systems, customers are supplied with services from suppliers both inside and outside of the enterprise.
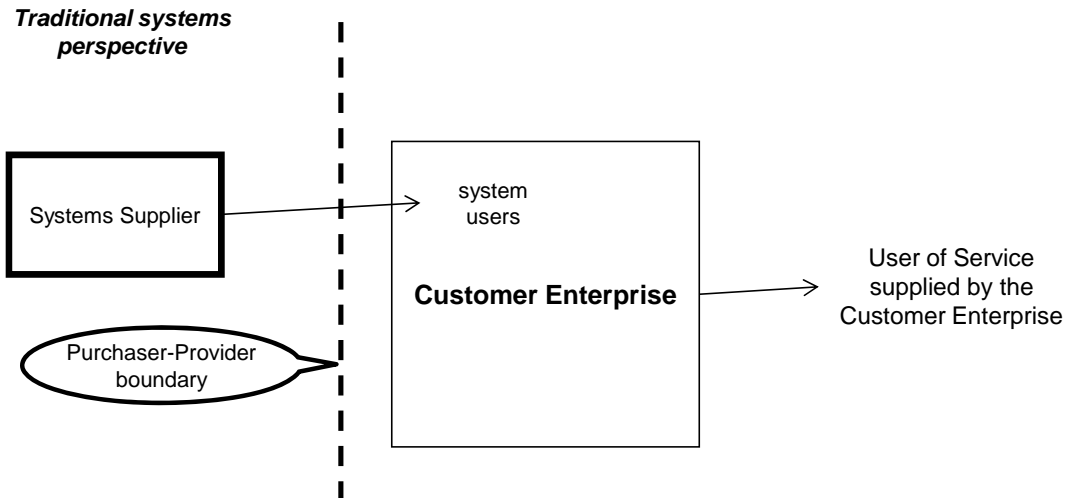
Figure 1:   Traditional Systems and Customer Enterprise Views of the Purchaser-Provider Boundary

The view in Figure 1 contrasts with the view of the customer enterprise in Figure 2 in which system suppliers come under the control of what we now call the SoS Enterprise, which does include the customer enterprise (typically as subcontractors). The purchaser-provider boundary moves between the SoS enterprise and the users of their *services*. This implies that the new boundary involves both products and services. This shift occurs because the system suppliers are now participating with elements of their customers to provide integrated solutions to those service users, who may or may not "see" the system supplier as a separate entity. The former customer-only enterprise now needs to be treated explicitly as a complex socio-technical system of systems.
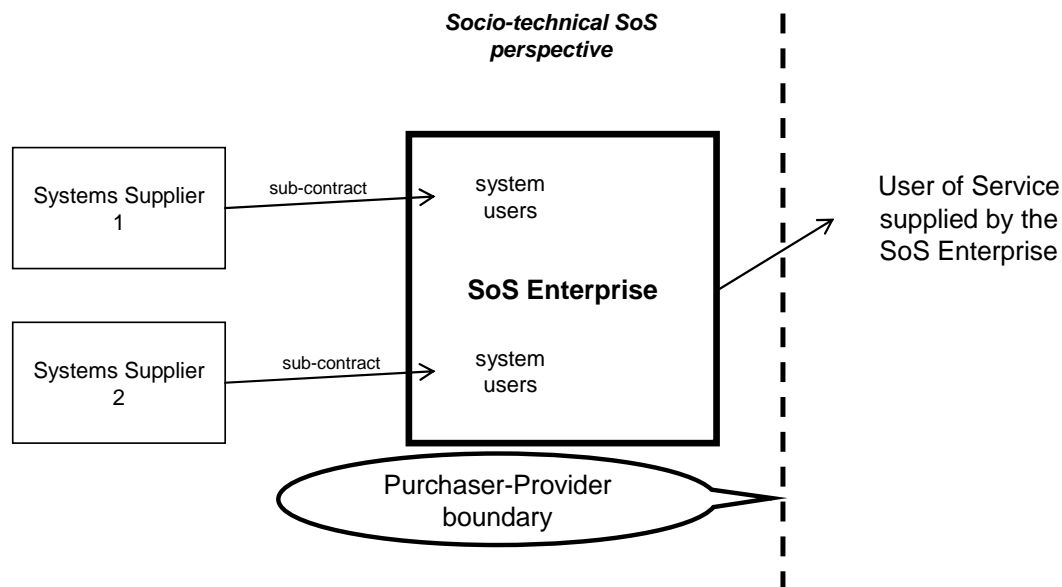
Figure 2:   Purchaser-Provider Boundary in Socio-Technical View of Systems of Systems

Even though it is crucial to determining the context in which demands arise, the purchaser-provider boundary of the SoS enterprise is often not clear to suppliers. Consider a hospital that has outsourced the maintenance of healthcare records. The various clinicians are the primary users of

the services provided by a hospital enterprise (for the benefit of the patient).[5] The provider of healthcare records is a supplier to the hospital enterprise, and the record supplier's customers are medical staff working directly under the authority of the hospital enterprise. Partner pharmacies that accept electronic prescriptions from the hospital cede some control to the provider of health-care records (they have provided the healthcare-record provider with access to certain of their internal records that are normally considered to be within the purview of the pharmacy) and thus are considered within the hospital enterprise. Note that online pharmacies that have no connections to the hospital's healthcare records are considered outside the hospital enterprise; indeed, they are competing with the services provided by the hospital enterprise.

The SoS Navigator approach helps leaders of an organization understand the SoS enterprise in which they participate, where their defining purchaser-provider boundaries are, and how to include the socio-technical elements in the way they define themselves as a system of systems. It also clarifies the role of the acquisition function in managing the supply side of the SoS Enterprise [Smith 2006].

A key implication of the shift in purchaser-provider boundary described in Figure 2 is that the relationships among suppliers, customers, and service users not only are different from those implied in Figure 1 but also shift as the demands of service users change and the capacity of the SoS Enterprise to shift its business models changes. A future technical note will deal explicitly with this implication through elaboration of the *value stairs* concept [Boxer 2007a].

2.2 SUPPLY, DEMAND, AND ORGANIZATIONAL CONTEXT

In our usage, *supply* refers to any of the enterprise participants that provide a system or a part of a system to system users (or integrators) who will employ it in the course of providing services to the service users. Examples of suppliers are COTS tool vendors and traditional system developers. *Demand* refers most immediately to the use made of the services provided by the SoS enterprise and the needs that generate those uses.[6] But it also refers to the more general operational environment (e.g., the constraints imposed by policy, regulation, etc.) in which those service users function.[7]

In the past, demand has been expressed (from the system supplier viewpoint) primarily through the notion of specified requirements. Using requirements as the sole expression of demand has led to difficulties in the past, but the practice has persisted in many environments as the primary communication vehicle across the traditional style of purchaser-provider boundary (Figure 1, page 6).

But, as both the systems of systems and their demand contexts—the contexts they are responding to with services—become more complicated, we need to move toward the SoS enterprise way of looking at the purchaser-provider boundary (Figure 2, page 6). Under these conditions, require-

---

[5] Direct patient access and use of their patient record is not far off, with the advent of both Google and Microsoft "vaults" for patient records.

[6] In this document, we use services in a traditional sense, not in the sense of services in a service-oriented architecture environment.

[7] An entity that *supplies* is commonly called a supplier. But the name for an entity that *demands* offers a slight problem in terminology, because although "demander" is a valid English word, its use is awkward. We prefer to substitute "user" as the entity that demands. We shall clarify among these terms when ambiguity might arise.

ments cannot adequately represent more than a snapshot of a subset of the demands that exist in the dynamic operational environment of users of services provided by the SoS enterprise. The concept of demand is therefore expanded beyond our traditional notion of requirements to include the

- context-of-use in which services provided by SoS enterprises will be used
- constraints of operations, regulations, and policy governing the use of those services

It has become very clear over the past several decades that turbulence in these contexts-of-use is giving rise to greater and greater demands by users on SoS enterprises [Emery 1965, Normann 2001]. Service users[8] are demanding specialized solutions in ever shorter time frames; they are also insisting that these solutions be continuously adapted to their changing and evolving contexts-of-use. The rapid evolution in cell phone technology over the past few years from wireless telephones to cameras to music players to internet devices to integrated sets of all of the above is characteristic of such a rapid evolution of services in response to new and changing forms of demand. A fundamental assertion of the SoS Navigator approach is that the contexts-of-use of the services provided by the SoS enterprise are all-important to understanding the demands to which the SoS enterprise must respond. This approach advances the idea that understanding the contexts-of-use on the demand side enables more effective response to the demand environment [Boxer 2006a].

Nuances of "Demand"

As formulated in the section above, we define *demand* as the particular ways in which service users define their needs, a concept more nuanced than the simple notion of requirements. The EMR service, for example, shows some of the ways in which demand can go beyond typical notions of requirement. The demand environment for EMR services includes the highly variable hospital policy environments where those services are deployed, which may necessitate some features of the EMR services to be "turned off" to meet local policy constraints.

Demand can be seen as symmetric or asymmetric. Symmetric demand describes an expectation by an SoS enterprise that a proportionate and stable relationship exists between the user's needs and the enterprise's understanding of those needs as expressed in the services it is prepared to provide. In other words, the enterprise offers a product or solution that is in its interests to provide and which it expects will fit stated (or unstated) demands of users (i.e., product or solution drives the use).

Asymmetric demand embodies the idea that an SoS enterprise must shape its services dynamically to meet changing demands in ways that may or may not fit its interests as it currently defines them. In responding to asymmetric demand, an SoS enterprise is accepting that its interests are served when the needs of the service user drive its understanding and interest. The service user's demand is specific to its experience of a particular context-of-use and that demand can rapidly evolve as the service user's context and understanding of its need changes. To meet such a rapidly evolving demand, a systems supplier within the SoS enterprise must also become flexible and adaptable. Furthermore, the service user's expectations for systems supplier flexibility can shape the demands they make on the SoS enterprise. It is important to understand that when a supplier

---

[8] The ultimate end user may be several layers removed from a given supplier, producing interesting challenges for understanding the customer-of-the-customer's (etc.) demand. This circumstance requires careful placement and recognition of observer perspective: multiple perspectives at different layers may be very appropriate.

within the SoS enterprise is able to dynamically support the satisfaction of one or more asymmetric demands being responded to by the SoS enterprise, we are not asserting that this converts the demand to being symmetric. Instead, satisfying an asymmetric demand is a continual process of defining the interests of the SoS enterprise in terms of its service users' interests and will be associated with continually changing responses to the users' dynamically evolving demands. Beyond a characterization of demand as symmetric or asymmetric, there are other nuances that affect complex systems. For instance, demand, whether symmetric or asymmetric, can also be predictable or unpredictable; its rate of change can be fast or slow. However, it is with the distinction between symmetric and asymmetric demand that we are most concerned, because in the context of complex systems, demand is largely asymmetric. Any asymmetric demand requires a dynamic responsiveness on the part of the SoS enterprise.

We seek, therefore, using the tools and techniques within SoS Navigator, to make clear how asymmetric demand will be present in different and dynamic ways, how demands may interact in a given context-of-use, and how SoS enterprises can find dynamic ways to meet those demands.

2.3   THE GAP BETWEEN SUPPLY AND DEMAND

Based on the expanded notion of demand espoused above, a gap between supply and demand emerges from the lack of direct connection between the service users and the systems that are provided by suppliers to support the SoS enterprises that are actually delivering services to those users. Complicating this separation and making it progressively more difficult to fully understand complex systems is that the service users' needs and the socio-technical contexts in which those needs arise are themselves constantly evolving, usually independently, with their future states largely unknown.

As a result, if service users' needs are sufficiently urgent but the systems and tools available to the SoS enterprise are inadequate to satisfy the needs of the task at hand, the SoS enterprise must find alternative ways to make do, by developing workarounds, modifying and adapting existing systems and tools, or finding other sources beyond the system suppliers they have used in the past. The modifications and adaptations that result from this scenario tend to be ad hoc. Thus, a doctor without emergency backup may make use of kitchen utensils and adapt the kitchen table to approximate sterile working conditions in order to meet the needs of patients presenting with medical symptoms. For an SoS enterprise where there is a considerable gap between supply and demand, such workarounds tend to become very expensive; the resultant drain on resources will ultimately constrain the ability of that enterprise to continually respond and adapt to new forms of demand [Boxer 2007a].

The SoS Navigator approach provides analytic tools that graphically depict this gap between supply and demand. Through use of SoS Navigator tools and techniques, we seek to define the degree to which the various participants may need to change behaviors in order to bridge that gap.

2.4   THE IMPORTANCE OF CONTEXT-OF-USE

In a specific context-of-use, a service user performs a task supported by the services of an SoS enterprise. These services themselves require a combination of socio-technical system elements that need to interoperate. That combination is often different than the one needed by other service users performing different tasks in different contexts-of-use. In effect, the SoS enterprise must be able to support dynamically changing use configurations of the systems that must come into play

for dynamically changing contexts-of-use. Similar to product configurations, a use configuration is a particular combination of tasks and constraints (as opposed to product elements) that support accomplishing a particular goal. Some of these use configurations can be known in advance; but one of the attributes of asymmetric forms of demand is that many of them can only be fully understood at precisely the time that the service user is faced with changing operational needs.

This concept can be illustrated by reference to the design of a certain class of agile fighter aircraft. These aircraft are designed to be unstable in flight; a computer must calculate in real time how to choose the correct physical configuration of relationships between its control surfaces, thrust, and the pilot's actions. The agility of the aircraft comes from the computer's ability to dynamically reorganize these configurations of use in real time. A different example can be seen in the way that an unmanned aerial vehicle (UAV) can reorganize its relationships to other components of a C4ISTAR[9] system in a way that is dynamically responsive to the needs of a battle commander.

The variety of demand situations that an SoS enterprise responds to often depends on how well it understands the variety of use configurations of its systems (1) that are possible and (2) that it chooses to support. A manufacturer of laptop computers, for example, could choose *not* to actively support the entire range of variation requested by the healthcare market. Demands may still arise for use configurations it does not support. But the manufacturer would not be the one to respond to those demands and would refer those clients either implicitly or explicitly to another source. This decision might well be made because the leaders of the laptop manufacturer do not want to invest in the learning needed to understand certain aspects of the healthcare market. This is a symmetric relationship between the laptop manufacturer and the demand from the healthcare market segment.

SoS Navigator analytic tools are aimed at engineering asymmetric relationships to demand. They make transparent (1) the variety of forms of demand that the SoS enterprise might be expected to respond to and (2) the corresponding variety in the use configurations that systems supplied by the SoS enterprise must be able to support. With SoS Navigator tools, the SoS enterprise can make decisions about what variety of demand situations it can and will participate in.

2.5   THE DOUBLE CHALLENGE OF GOVERNANCE AND DEMAND

In a complex system, governance is critical. For our purposes, *governance* is the way power is distributed, whether among suppliers or users, in a given enterprise in response to demand from outside the enterprise. We can place governance, in its common senses of control and authority, in relation to three other concepts: (1) the aggregate collective resources of the SoS enterprise; (2) the demand from service users within their context-of-use; and (3) the ability of the supplying SoS enterprise to synthesize multiple solutions with multiple use configurations. The last concept refers not merely to traditional engineering skill but also to the many ways an enterprise can orchestrate and synchronize resources to respond to a particular context-of-use. For example, the enterprise can choose to co-locate staff resources at an operational site or may only make them available at the corporate headquarters.

Governance maintains balance among those three concepts. Under centralized governance, a single source of authority exercises control over the

---

[9]   C4ISTAR represents the military functions defined by C4 (Command, Control, Communications, Computers), I (military intelligence) and STAR (Surveillance, Target Acquisition and Reconnaissance).

- resources of the enterprise (e.g., staff, IT systems, specialized tools or labs)
- ways that system users within the enterprise use resources and synthesize solutions (e.g., via integrated product teams, field offices, or virtual working groups)
- ways service users make use of the enterprise's services to meet demand (e.g., as part of a larger collaborative/joint team to meet a specific mission)

In *centralized* governance, differences and problems between suppliers and customers can be resolved—and balance maintained—by the single source of authority. Under conditions of centralized governance, power is held at the top of an enterprise and is expressed in the form of a hierarchical decomposition of roles through which individuals can be held accountable for their behavior.

However, it is likely that meeting service user demands may involve multiple SoS enterprises—in acquisition, where large systems are built by several corporations, and in operation, as when elements from different branches of the armed forces engage in joint operations. In a multiple-enterprise context (and even for large, nominally single enterprises), different centralized governance structures are almost inevitable. Where such different governance structures exist, one significant challenge is to assert a single source of authority over different, and sometimes competing, constituents, even in relation to a single end-user context [Morris 2006].

Under conditions of asymmetric demand, however, the exercise of authority must become dynamic and *decentralized*, enabling power to be exercised at the edge of the SoS enterprise[10] [Boxer 2007b]. In Figure 2 (page 6), roles operating at the edge of the SoS Enterprise are those working across the purchaser-provider boundary most directly. This decentralized form of governance permits the service users' demands to influence the ways the enterprise's expertise is applied. It also provides a means of dynamic alignment between the enterprise and service user that is not usually found in a centralized governance environment. For example, if a field engineering organization that works with diagnosing, supporting, and maintaining complex hardware systems is required to have every proposed fix or repair, even if it fits within current tolerances, approved by a central engineering organization, the centralization of that approval is likely to create lag times that translate into perceived wasted time/effort on the part of the user waiting for the repairs. If, however, the central engineering organization cedes control over all changes that do not violate function, form, and fit requirements to the field engineers, they have moved some of their control to the engineers who interface directly with the repair service users, enabling their fields engineers "at the edge" to make more effective use of their time and to improve the service to their users. It also creates a knowledge management problem as the engineers must learn directly from the diagnostic experience of one another.

The response by the SoS enterprise must be inherently based on the experiences of the service users where the demand is encountered (e.g., the first fire officer who arrives on scene). This need for the SoS enterprise's response to be based on the experience of service users in a specific context may well require the enterprise to change or realign its resources to meet the new demand.

The SoS enterprise is therefore faced with a *double* challenge: needing to cross the governance structures of multiple enterprises while simultaneously responding appropriately to asymmetric

---

[10]   "At the edge" is a common military way of referring to the users where the demand (e.g., threat to the enterprise) is encountered, often in battlefield conditions. For non-military situations, such as healthcare, the edge is where clinicians meet the demands of patients.

demand (see Figure 3 [Boxer 2006b]. The SoS Navigator approach is concerned with the response of SoS participants to this double challenge—its nature and its difficulties.
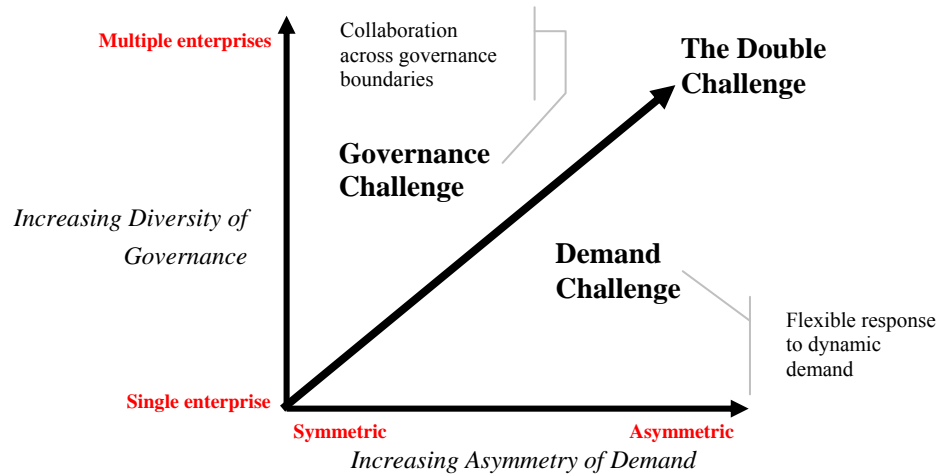
Figure 3:   The Governance-Demand Double Challenge [Boxer 2006b]

2.6   THE IMPLICATIONS OF DECENTRALIZED GOVERNANCE

For one enterprise alone, moving toward decentralized governance is difficult; for multiple enterprises, with many governance structures that are engaged in multiple projects, it can appear insurmountable. Moving from centralized to decentralized governance is a fundamental change, and it implies that there now must be a dynamic set of relationships among the elements of the SoS enterprise. Those relationships need to be kept in balance, since power—traditionally exercised by a central authority at the top of the enterprise—now flows out to the edge, to those that respond to service users. This balance must ultimately be based on judgments about what constitutes a sustainable business model for the SoS enterprise: whether it should put resources first or relationships to demand first.

Decentralized governance is part of the notion of *distributed collaboration*, which the SoS Navigator approach advances as an effective means to meet the double challenge [Boxer 2005]. Distributed collaboration is a governance and synthesis style of complex socio-technical systems. Through distributed collaboration, the constituent elements of these systems—technical, organizational, or both—can effectively respond to heterogeneous demands from a set of (often diverse) users' (asymmetric) demands, even though they are independently managed and evolving. Responding to asymmetric demands through distributed collaboration is a challenge even for high-performing, high-capability organizations.

SoS Navigator tools and techniques provide insight into the support structures a client has for governance. An SoS Navigator team can create a *footprint* of current support with respect to centralized and decentralized governance, which allows the organization's governance structures to effectively respond to asymmetric demand environments.

2.7   REQUIRED AGILITY

A distributed collaboration approach fuels the SoS enterprise with the agility it needs to support the variety of use configurations called for by a dynamic environment [Boxer 2006c]. This agility drives the SoS enterprise to recompose itself according to demand-in-context instead of statically

forming around supplier capabilities. The agile SoS enterprise is characterized by its ability to recognize and adapt to unpredicted demands [Brewer 2006, Ashby 1963]. SoS Navigator tools allow organizations to understand the elements of agility, such as

- reuse potential
- cost of alternatives
- prioritization of value
- labor versus automation tradeoffs
- interoperability risks

It is worth noting that not all situations require the level of agility described above. It is equally important to understand the times when different types of agility are required within an SoS enterprise, so that a balance between agility and other organizational drivers can be sustained.

2.8 INTERRELATED NATURE OF THE FUNDAMENTAL CONCEPTS

The preceding sections describe the fundamental concepts in which the SoS Navigator approach is grounded, as summarized in Table 3. Although we have explained them separately, the principles suggest a coherent and integrated whole:

1. Central to the SoS Navigator approach for understanding complex systems is that supply-and-demand-in-context reveals all. The relationship of providers to demand becomes *asymmetric* when complex systems of systems involving multiple organizations exist in a turbulent context-of-use.

2. In turn, all concerned—suppliers of solutions, users at the operational edge, authorities at the top, and the hierarchical governance structures—must jointly exercise forms of *decentralized governance.*

3. Hence, in an asymmetric demand context, a *dynamic balance*—reflected in dynamic, decentralized forms of governance—among the various players in an enterprise is vital. This is the key notion: a balancing form of governance is needed that exercises managerial judgment and coordinates, guides, and most importantly, gives *real authority to those best equipped to judge the particular nature of demand—the people at the edge of the enterprise.*

4. Dynamic balance across the SoS enterprise provides the agility, flexibility, and adaptability to dynamically orchestrate and synchronize solutions in response to service user demand.

The needed balance must be negotiated among the purchasers and providers in a particular situation and constantly re-examined to allow the SoS enterprise to quickly react to rapidly shifting contexts-of-use. Our use of the navigation concept and its attendant notion of navigating through a complex and stormy sea of change emerge from this fundamental assumption that the needed balance is dynamic and evolving.

Table 3:   Fundamental Concepts and SoS Navigator Assertions

Concept	Description	SoS Navigator Assertion
SoS enterprise and the purchaser-provider boundary	The SoS enterprise includes all the socio-technical elements that are on the provider side of the purchaser-provider boundary in complex systems of systems (see Figure 2).	The SoS Navigator approach helps leaders understand the SoS enterprise they partici-pate in, where the purchaser-provider boundary is in their situation, and the way to focus on the socio-technical elements that are on the provider side of that boundary in their environment.
Supply, demand, and organizational context	Satisfying an asymmetric demand is an ongoing process of continually changing responses answering dynamically evolv-ing, unpredictable demands.	SoS Navigator tools can make clear how asymmetric demand will be present in differ-ent and dynamic ways, how demands may interact in a given context-of-use, and how SoS enterprises can find dynamic ways to meet those demands.
Gap between demand and supply	The gap between demand and supply is evident in the disconnection between systems suppliers and the users who daily make decisions about how they will per-form their jobs on the demand-side.	Through use of SoS Navigator tools and techniques, we seek to define the degree to which the various participants may need to change behaviors in order to bridge that gap.
Importance of context-of-use	There are dynamically changing demand situations that drive the required agility.	SoS Navigator analytic tools are aimed at helping clients engineer asymmetric relation-ships to demand. They make transparent (1) the variety of forms of demand that the SoS enterprise might be expected to respond to and (2) the corresponding variety in the use configurations that systems supplied by the SoS enterprise must be able to support.
Double challenge of governance and demand	It is necessary to cross the boundaries of the governance structures of multiple enterprises to respond appropriately to asymmetric demand.	The SoS Navigator approach is concerned with the response to this double challenge— its nature and its difficulties.
Implications of decentralized gov-ernance	There must be some balancing force in place that maintains a dynamic form of governance throughout the SoS enter-prise.	SoS Navigator tools and techniques provide insight about the support structures a client has for centralized and decentralized gov-ernance.
Required agility	There is flexibility and adaptability needed to dynamically orchestrate and synchro-nize solutions in response to edge-driven demands.	SoS Navigator tools allow organizations to understand the elements of agility, such as reuse potential, cost of alternatives, prioriti-zation of value, labor versus automation tradeoffs, and interoperability risks.

2.9   SOME IMPLICATIONS OF THE FUNDAMENTAL CONCEPTS

The concepts fundamental to SoS Navigator have several implications in the areas of process, economics, interoperability, engineering, and collaboration.

2.9.1   Process Implications

The major implication of decentralized governance is that the individual at the edge of the SoS provider's enterprise, the one most directly facing the service users' demands, must be empow-ered with required authority and be provided with the means to rapidly clarify the appropriate

tools and systems needed to meet service user demands. This empowerment, and, indeed, the entire question of dynamic balance among all elements heretofore discussed, is a matter of process.

With centralized governance, process considerations are largely derived from the decisions already made about the enterprise's business model. We can describe the relevant processes as the performance of the following steps:

- decide what the demand is, largely in terms of requirements and based on the business model of the enterprise
- develop an implementation of those requirements, in the use of which the individuals (including those at the edge) can be trained
- deploy that implemented functionality and allow demand to drive change requests, though it will not necessarily drive the responses to those requests

However, in conditions of decentralized governance, a very different process must be used, one that accepts that power must flow out to the edge. This means that decisions traditionally made based on a power and authority basis are now made based on a role in relationship to the service user situation and on know-how related to satisfying a particular service user demand. In such a process, where relationships to demand are asymmetric, the service users must have access to solutions from suppliers within or beyond the existing boundaries of the enterprise who can furnish them in an agile manner. In this kind of process, governance includes a clear understanding of the communities involved, transparently sharing responsibility and accountability. The process must also manage dynamic alignment of roles and governance structures:

- establishing boundaries on the relationship of the various providers to service users
- deeply understanding the service users' context-of-use within the established boundary
- coordinating and synchronizing enterprise expertise and assets to meet service user demands
- determining the value proposition to service user and provider

The nature of the process steps to achieve this is likely to vary sharply between different situations.

2.9.2 Economic Implications

For any SoS enterprise, whether the context is asymmetric or symmetric, there are certain costs associated with setting up and maintaining its identity: in the military, defining its mission; in industry, establishing the market it is chartered or intended to serve; and so forth. These are referred to as *alignment costs* and are separate from the *transaction* costs that the enterprise then engages in (i.e., as a supplier to its user community). Under symmetric conditions, once an enterprise has been set up, the alignment costs (such as establishing and evolving employee training and policy and procedure) that the enterprise incurs primarily stem from maintaining that identity. But when demand is asymmetric, the identity of the SoS enterprise becomes more fluid (e.g., markets shift, different contexts arise), so that the enterprise incurs continuing alignment costs associated with accommodating itself to those changed forms of demand. For example, the ways in which the operational uses of UAVs are evolving over time is changing the nature of the services that the UAV Service must provide in support of Command. As a result, the SoS enterprise providing the UAV Service has to redefine itself from (for example) being a provider of an airborne observation platform to being a distributor of timely and relevant pictures. This need to redefine identity funda-

mentally changes the business model being used by the SoS enterprise [Boxer 2008]. The growth of the costs associated with such dynamic realignment can be very great when compared with the costs of its transactions. Generally, these costs are only included in the way the enterprise manages its economics at times of major step-changes in its overall identity.

2.9.3   Interoperability Implications

Regardless of how the functionality of systems of systems may initially be defined, service users will inevitably find new and unanticipated ways of expecting the functional elements to interoperate. To accommodate the inevitability of service users finding different ways to combine system elements, the enterprises as well as the constituent systems must be sufficiently agile to permit their rapid recomposition. Thus, system elements must be able to be used in combinations that were not originally planned for, and elements need to be able to be interfaced in ways that the original designers never anticipated (including those not presently sourced from within the enterprise). Note that we are *not* referring here to creating additional functionality per se but rather to how various functional elements can be composed and recomposed in relation to one another.

2.9.4   Collaboration Implications

In an asymmetric context, there will be many forms of collaboration, each of which must be suited to and aligned with particular forms of demand. These different instances of collaboration can be organized and engineered to maximize agility (or optimized to determine required agility). SoS Navigator uses multi-layer models to represent and subsequently reason about many aspects of the SoS enterprise and its situation (interoperability risks, end-to-end demand response, component granularity, interface requirements, and the like).

2.9.5   Engineering Implications

The ways in which functional elements can be composed and recomposed in relation to one another, like LEGO® bricks, depend on the way the functional elements are themselves defined. The greater the variety of use configurations that a system of systems must support, the more important it becomes to define the individual functional elements (i.e., their granularity) in ways that maximize their use at the composite level. The SoS Navigator approach provides ways of (1) representing the required variety, (2) analyzing the composite uses they give rise to, and (3) showing how the underlying functional granularity interacts with this variety of uses.

3   SoS Navigator Approach

The SoS Navigator approach includes a process and a supporting set of tools. Together, they can be used to analyze a client's present circumstance and recommend transformations that better accommodate the needs of asymmetric demand and decentralized governance. The *client* here is assumed to be an SoS enterprise, so that we can now refer to its service users as its *customers*. The tools include a rich set of modeling techniques. In this section, we summarize both the process and the supporting tools.

The SoS Navigator process framework has two parts: (1) the framing process and (2) a learning/transformation cycle. The framing process focuses on providing understanding, along multiple dimensions, of how the client organization is an SoS enterprise, potentially in collaboration with other SoS enterprises[11] [Anderson 2006]. SoS Navigator framing enables the client to decide to what extent it needs to adopt new business models and strategies that require distributed collaboration. The composition of the SoS Navigator learning/transformation cycle, for the client, depends on the outcome of the framing process. To the extent that change is necessary, a targeted learning and transformation cycle needs to be undertaken. If the decision is that the client is not engaged in an asymmetric demand situation, it is likely that more traditional change management approaches to deal with the client's problem would be undertaken. Some individual SoS Navigator tools might be used in this instance, but not in the integrated fashion that would be applied in an asymmetric demand client situation. Table 4 summarizes the parts of the process.

Table 4:   Top-Level View of Navigator Process

Framing Process	Learning/Transformation Cycle		
• Understand the relevant participants • Decide if SoS enterprise needs to respond to asymmetric demand (If *yes*, proceed to Learning/Transformation Cycle.)	• Transform business model to support dynamically responding to asymmetric demand	• Define organizational and technical changes needed	• Support integration and institutionalization of changes

3.1   THE FRAMING PROCESS AND SUPPORTING TECHNIQUES AND TOOLS

Much of the framing process is diagnostic. After studying the issues presented by the client organization, the SEI's SoS Navigator team selects one or more diagnostic techniques to gain a clearer picture of the supply and demand sides of the client's situation. The steps in the framing process and their associated diagnostic techniques are summarized in Table 5.

---

[11]   In Section 2, we focused primarily on an enterprise as a whole. Most enterprises are themselves socio-technical systems of systems, so that when applying SoS Navigator processes and tools, we find ourselves working with subsystems of the entire enterprise. So we discuss the use of tools and methods in this section in relation to a client organization, which is always within the context of an enterprise as a whole as we discussed in Section 2.

Table 5:   SoS Navigator Framing Process Steps and Supporting Techniques

Framing Step	Sample Questions this Step Answers	Techniques	SoS Navigator Activities
Identify the variety of stakeholders and the demands they currently put on the SoS enterprise	Who are the influences on getting the solutions out to the client's customers? How do they affect each other and the client organization?	Collaboration Stakeholder Analysis Value Network Analysis	• Looks at four types of stakeholder and their relationships to help the client understand where appropriate and inappropriate influences are affecting its ability to deliver effective solutions into its demand environment. • Looks at particular stakeholders and the value exchange between them and the client organization for relevant patterns and misalignments.
Identify the influences on current and future demand from the environment in which the SoS enterprise operates	What is the client's proposition as to how it responds to demand? What does the variety of the demand environment look like?	Proposition Analysis	• Looks at four types of possibility for value propositions (replication, capability, knowledge, and problem) and provides feedback on how the client might improve its value proposition to be more effective in responding to its demand environment.
		Scenario Analysis	• From the external environment inward, formulates a set of scenarios that reflect today's variety of contexts in which demands are arising, or the future's, or both. (These scenarios can be used to model different types of demand situation and to informally test different strategies for relating to those demands.)
Analyze the governance and support structures involved in the SoS enterprise and their (mis)alignment to the varieties of demand placed on it (This is the conceptual version of an analysis that is investigated in more depth during a learning/transformation cycle.)	Where are the different centers of power within the client organization and the key players it collaborates with in the SoS enterprise? In what ways are the client's accountability and responsibility structures congruent with its intended proposition within the demand environment?	Influence Map Analysis	• Captures aspects of the social network that is present in the organizations participating in systems of systems. (Can leverage work done in the Collaboration Stakeholder Analysis or be conducted independently.)
		Congruence Analysis	• Looks at where the structures of the organizational architecture support or contradict the desired propositions to be offered in the demand environment. (This analysis depends on the Proposition Analysis having been completed, and also benefits from the Center Push/Edge Pull Analysis having been done.)
		Value Stairs Analysis	• Characterizes the purchaser-provider boundary with relation to the possible types of demand response. • Allows identification of a strategy ceiling, the level on the value stairs matrix above which the enterprise chooses not to define itself by reference to its competitors and customers.
Analyze SoS enterprise resources (elements, infrastructure, assets) in relation to the varieties of demand	Does the technical asset base the client organization is using to respond to demand have sufficient flexibility?	Asset Analysis	• Examines representative elements and configurations of the socio-technical assets that make up the client's offerings to determine where there may be gaps in the asset development strategies in relation to the demand environment. (Often, modeling techniques are used here to provide a picture of potential interoperability gaps that are inherent in the development strategy.)
Analyze how the variety of demand needs to be supported by varieties of relations among governing entities, infrastructure capabilities, and functional elements	In what ways is the client organization's governance strategy driven from the center or decentralized to "the edge"?	Center Push/ Edge Pull Analysis [Boxer 2008]	• Provides insight about the support structures a client has for centralized and decentralized governance. • Can be combined with other analyses to create a profile of current edge/center supports versus those needed to effectively respond to the demand environment. (The SoS Navigator Team adapts a military system called the Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities [DOTMLPF] wheel.[12])

The choice, sequencing, and timing of the analyses summarized in Table 5 depend on the context as presented by the client. The goal is not to complete all the analyses, unless all are needed. Rather, the goal is to use those analyses that are relevant to obtaining a sufficient picture of the client and its relationship to the problem situation. Through the appropriate analyses, we determine whether

1. the organization is involved in a distributed collaboration, asymmetric demand situation

2. the organization needs to or is ready to take steps to be more effective in its situation

Where both of those conditions are found to exist, the framing process yields a restatement (a reframing) of the problem situation in terms of what has been discovered about the organization and its relationship to its demand environment. This reframed problem can then be used to enter into the activities of the learning/transformation cycle. Where both do not exist, the engagement would not be considered an SoS Navigator engagement and the team and client would decide on what kinds of approaches might be more suited to the client setting.

The suite of tools and techniques used to support the framing process is expected to grow as the SEI SoS Navigator team works in a greater variety of client situations. We will establish a toolkit for the framing process and transformation cycle, which adequately supports a wide variety of enterprise situations. Some of these tools will be more easily conducted "at home, on your own" than others. As we identify promising self-administered techniques, we will document them in SEI technical notes.

3.2   THE LEARNING/TRANSFORMATION CYCLE

Following the framing of its situation in terms of distributed collaboration and asymmetric demand, the client can decide whether moving to a dynamic business model (usually one that embodies decentralized governance) must be taken up in the interest of the enterprise. The SoS Navigator learning/transformation cycle supports the client in understanding and making the necessary changes.

Three broad categories of tasks guide the transformation. Table 6 summarizes the broad steps in the learning/transformation cycle and the activities that might take place within each one. This part of the process is primarily a consultative one, so each situation will apply the broad steps differently. As we identify patterns in applying these steps, we will document them as part of the planned SoS Navigator Analytical Framework.

Table 6:   SoS Navigator Learning/Transformation Cycle

Transformation Step	Sample Questions this Step Answers	Possible Subsidiary Activities
Identify the business and technical strategies to transform the organization's business model to support distributed collaboration in asymmetric demand environments, based on needs identified in the framing process.	How does my business and technical strategy need to change to accommodate my demand environment?	• Establish how the contexts-of-use are organized • Establish leading indicators for direction of possible futures • Understand data fusion issues and related asset characteristics • Describe cohesion of the enterprise • Define structures of accountability within the enterprise
Work through the changes needed in organization architecture and support structures to enable effective distributed collaboration in asymmetric demand environments, via technical and adoption feasibility pilots.	What is the most productive way for me to approach the needed organizational and support architecture changes?	• Define required variety of demand for success • Align needed functionality to required varieties of demand • Define and pilot processes of alignment for the enterprise • Establish operational profiles
Integrate and institutionalize the changes needed to effectively support distributed collaboration in asymmetric demand environments on an ongoing basis.	How do I ensure that the needed changes "stick" within the fabric of the organization over time with sufficient flexibility?	• Identify and institutionalize configurations specific to a particular context-of-use • Incorporate relevant scenarios in strategic planning processes • Close interoperability gaps among assets • Identify sources of competitive advantage

The diagnostic and analytic tools and techniques of the SoS Navigator approach make considerable use of modeling, since an organization must have a clear picture of the forces that are at work in complex systems of systems if they wish to participate effectively. The primary modeling technique used, Projective Analysis (PAN),[13] goes beyond typical business and organizational modeling techniques by addressing both supply- and demand-side system elements and structures. It also addresses some aspects of typical system functional modeling, allowing a single view of both the supply- and demand-side influences on a system-of-systems situation [Anderson 2006].

3.3   SUMMARY OF SOS NAVIGATOR PROCESSES AND TECHNIQUES

By using a process that contains rich diagnostic and analytic tools, we seek to provide novel insights into:

- the realities of demand for the actual end users
- how suppliers and providers are organized in themselves, in relation to demand, and in relation to changes in demand
- the services required to respond to demand
- how those services are composed into capabilities
- how those capabilities are fielded (deployed)

---

[13]   © Boxer Research Ltd 2006. Permission to use PAN technology is granted under license to Carnegie Mellon University.

- how the fielded capabilities are synchronized to produce desired effects
- the drivers of effects that are of particular significance to the client's SoS enterprise

Most of the tools used are employed initially during the framing process. Some of those tools evolve into further use in the learning/transformation cycle.

There must be strong competitive reasons for shifting from a central governance model—dominated by high-level governance over organizational capabilities and resources—to a decentralized one that can accommodate dynamic, demand-driven responses to changing contexts. Such a shift has to be driven directly by the nature of demand itself: the drivers of change have to be the needs of the individuals at the edge of the enterprise. Even where there are such reasons, it does not mean that the whole enterprise has to change. An iterative approach should be taken, since the whole change usually cannot be effected in one cycle. It is also better to work from the strongest demands first and allow the learning derived from responding to these demands to shape subsequent cycles.

With the decentralized governance that is generally needed to support distributed collaboration in asymmetric demand environments, the process considerations themselves become central to sustaining a dynamic balance among four elements of the enterprise (governance, demand, resource infrastructure, and collaborative processes). We have presented information on governance and demand in Section 2. Resource infrastructure is the totality of human, material, and intellectual capital that is available to the enterprise to synthesize products and services. Collaborative processes are those processes that are used to synthesize services across governance boundaries to provide services needed within the context-of-use. In Section 4, we summarize three case studies to illustrate how these considerations were addressed and how the tools and techniques were used.

4 Case Summaries

In this section, we provide three brief descriptions of SoS Navigator processes or techniques in use. These are based on actual client engagements but are sanitized and abstracted. As a preface to these brief descriptions, we stress that the decision to treat demand as necessarily asymmetric is ultimately based on economic and competitive factors. It reflects the combined pressures of suppliers within an SoS enterprise needing to get closer to the real demands being felt at the edge of the enterprise and the escalating costs of aligning that enterprise to respond to those demands.

In the case study summaries that follow, we have provided more narrative descriptions that give an overall impression of the kinds of activities in which we were engaged. In each example, a variety of SoS Navigator techniques were used. We will return to these cases in future technical notes and elaborate on details related to particular technique use and process steps, as appropriate.

4.1 PROVIDING CARE FOR CHRONIC CONDITIONS[14]

A national funding agency sought to improve the quality of the care it provided to about 1.2 million patients through a large number of clinics [Boxer 2006d]. The clinical service was the client SoS enterprise, and its service users were the patients. The service treated chronic, long-term conditions and had been organized to minimize the cost of treatments, in terms of the products used and the use of clinicians. Previous studies established the need to optimize care through the life of the patient's condition, not simply to minimize treatment costs.

The improvement project was planned over a three-year cycle. The first phase involved a framing process to establish the technical feasibility of the proposed approach to changing the clinical service's role in treating patient conditions. After that phase, pathfinder projects would establish the adoption feasibility of the approach. We worked with nine clinics, chosen to represent a significant variety of approaches to organizing and delivering the clinical service.

The SoS Navigator framing process took about eight months and involved three clinics overseen by the agency, while the subsequent learning/transformation cycle activities spanned a period of approximately two years. During the framing process, a number of aspects of the service and its organization were analyzed using a range of SoS Navigator diagnostic and analysis techniques (see Table 4), including:

- analysis of effects ladders and propositions
- stakeholder collaboration analysis and modeling of the processes of supply-demand alignment
- agility analysis of the existing systems infrastructure and definition of clinicians' data fusion needs
- analysis of the governance mechanisms and the economics of how services were organized

As a result, we established the viability of making changes on both the supply and demand sides: innovations were needed in the protocols covering treatment and referral; there were fundamental gaps in the methods of data fusion needed to support and sustain these changes at the level of the

---

[14]   Although this case preceded the incorporation of ideas from Boxer Research Limited into SoS Navigator, it is included here with Phil Boxer's permission to illustrate how these concepts can be used.

clinic; and the agency-level approach to the procurement of the service itself needed an approach that focused on the costs of treating patients through the course of their condition throughout their lives, not just episode by episode. It was this shift to a through-life focus that made the demands on the clinics explicitly asymmetric: instead of providing standardized treatments, the clinic had to manage individual patients' conditions.

During the subsequent learning/transformation cycle, we executed adoption feasibility projects (called pathfinder projects) to address the services being provided by six different clinics within their respective healthcare organizations. Those clinics were chosen for the diversity of patient ages (from 20 to 90), conditions (from flat feet to osteoarthritis and diabetes), and clinical organization sizes (from small primary care clinics through to major teaching hospital facilities supporting a regional patient base). Each pilot we conducted provided different ways for the national agency to understand the alignment between suppliers and users and represented different potential business models that would address the issues established in the framing process. In each of these pathfinder projects, we used various SoS Navigator tools and techniques to establish the economics involved in delivering the service, the processes of patient referral, the clinic models, and the information support. Based on these, we defined the organizational and technical changes needed. Implementation of the projects commenced as the need for each change emerged in the organizations, with particular attention being paid to how likely each change was to be institutionalized within the organization and agency.

The outcome at the agency level was twofold:

1. Significant opportunities for cumulative savings were identified as the governance shifted to a decentralized approach.

2. A new set of challenges for transitioning the learning to other parts of the national organization was identified.

Judged as a success by the management directly involved with the services, together with the clinicians and their professional body, the overall project raised new challenges at the agency level for the approach to institutionalizing change. For example, the differences in accounting approach to support decentralization versus the one in use that supported centralized accounting presented challenges at the agency level because of the way the new approach cut across the boundaries of institutions whose systems were normally kept separate. In effect, the existing governance framework determined levels of clinical activity centrally. Although the pathfinder projects established that the system-of-systems cost would be lower if governance were decentralized and aligned to managing the through-life costs of patients' conditions,[15] the funding agency was not (yet) in a position to implement these changes.

---

[15] The U. S. Institute of Medicine established the same potential outcome [USIM 2001].

Table 7: Summary of Providing Chronic Care Engagement (Three-Year Period)

	Scheduled/Executed Activities	SoS Navigator Tools and Techniques
SoS Navigator Framing Process		
Understand supply and demand basic relationships	Establish the need for a clinical approach to managing through-life care episodes	Proposition Analysis, Effects Ladder, Collaboration Stakeholder Analysis
SoS Navigator Learning/Transformation Cycle		
Transform business model to support dynamically responding to asymmetric demand	Analyze the referral pathways and the existing methods of clinic management	Value Stairs Analysis, Center Push/Edge Pull Analysis, Effects Ladder
Define and pilot organizational and technical changes needed	Pilot the support platforms, episode and referral protocols, and procurement practices	
Support integration and institutionalization of changes	Summarize the economic payoffs and change processes Recommend changes to working practices	

4.2 EVOLVING MILITARY OPERATIONS

This case involved a military support unit that was facing two kinds of change [Boxer 2006e]. First, it was being expected to extend the range and scope of its roles in support of overseas operations; it now would interoperate with other units beyond its current scope. Second, the software engineering on which the unit was dependent was being upgraded to include a much higher degree of automation. The client SoS Enterprise was therefore the military support unit, and its service users were the military operational users of its support capabilities. The problem as initially defined by the support unit was to identify what risks the automation upgrade posed to the armed service's ability to sustain its support capability over several future years; in addition, we were asked to recommend approaches to mitigating the identified risks. Thus the problem was defined in terms of the relationship to the systems supplier. The framing process took about one month, with the subsequent activities spanning two additional months. The time span was therefore at the opposite end of the spectrum to the healthcare experience described in Section 4.1.

During the framing process, we focused on the alignment between the changing nature of the demands on the unit's organizational and technical structures. Since there were multiple communities involved with acquiring, sustaining, and operating the capabilities supported by the unit, we also examined the methods of governance. These methods defined how the communities could cooperate to deliver the needed technology upgrade. We noted that there were no obvious processes for resolving differences of approach among these communities. We saw this to be the core challenge to their managing interoperability risks through the life of the unit.

When we moved into the learning/transformation cycle, we analyzed more closely the different approaches used among the communities. We identified three different perspectives by which the capabilities provided by the operational unit could be analyzed:

1. the physical nature of the capability

2. the capability's role in supporting decision-making

3. the use of the capability to generate operational effects

We drew together members of the different communities in workshops that focused on each of these perspectives. We then modeled their understanding of the technical aspects of the capability being provided by the operational unit, the unit's economic and funding drivers, and how acquisition decisions were made.

We examined the output of these workshops to identify the major structural gaps in the alignment among the different parts of the operational unit. The analysis related these gaps to the double challenge: the way the operational unit was managing its different communities and the operational demands being placed on them. These gaps reflected the fact that the particular interoperability risks identified were failing to be addressed. We concluded that, in order to bridge this gap, the operational unit needed to embrace a more adaptive approach that would

1. manage the linkages between needed architectural changes and the overall costs of the capability provided by the operational unit

2. require fuller analysis of the changing mission environment that the unit was expected to support

Fuller analysis would then provide a basis from which to select mitigation strategies for the interoperability risks emerging from the changing mission environment. Our part in the study concluded after delivering the recommendations.

Table 8:   Summary of Evolving Military Operations Engagement (Three-Month Period)

	Scheduled/Executed Activities	SoS Navigator Tools and Techniques
SoS Navigator Framing Process		
Understand supply and demand basic relationships	Establish the current and through-life support challenges facing the operational capability	Influence Map Analysis, Congruence Analysis, PAN models, Interoperability Risk Analysis
SoS Navigator Learning/Transformation Cycle		
Transform business model to support dynamically responding to asymmetric demand	Analyze the technological, organizational, and demand characteristics of sustainment	
Define and pilot organizational and technical changes needed	Analyze the interoperability risks to sustainment and proposing mitigation strategies	[Our part in the study ended after we delivered recommendations following the framing process]
Support integration and institutionalization of changes	Recommend fuller follow-up on through-life economics, engineering, and demand variety	

4.3 ADDRESSING MASSIVE CONTEXT CHANGES

The initial problem in this case was expressed in terms of the information and technological support needed for managing local and regional wildland ecosystems. The client organization was an agency whose task was to enable local communities to manage and mitigate risks to life, property, and local economies related to the emerging characteristics of these ecosystems. To do so, these local communities needed access to service providers that could make available a comprehensive risk analysis and management service, supported by a large collection of tools and technologies. Multiple organizations were tasked with providing this service, a situation made more difficult by the dynamic nature of the ecosystems (e.g., many are under pressure from population movement and climate change). These service providers varied from being departments of national agencies to local collaborations funded directly by grants. The SoS enterprise was this community of service providers. Their systems suppliers were the providers of tools and technologies, and the service users were ultimately the local communities at risk. The client agency was expected to reflect the interests of this range of stakeholders in the larger task of managing and mitigating risks.

As part of the framing process, we examined several elements of the overall situation, most notably the existing governance models and the types of demand being presented by the ecosystems within the management purview of different service providers. We saw that a significant gap had opened between the organizations supplying information and technological support (the systems suppliers) and the ways this support could be orchestrated and synchronized by the service providers "at the edge" of the enterprise in response to the varying needs of local communities.

One solution suggested by the client agency was that this gap could be filled by a common model of all the supporting tools and technologies. However, our analysis suggested that such a model would be insufficient to fill the gap because of the dynamic variability and complexity of the actual demands being encountered in the field. We therefore focused on identifying and characterizing the patterns in the varieties of demand and the changes needed in the service providers to support this variety: the collaboration processes, the technical architectures needed to support distributed collaboration, and the engineering of the tools and techniques that supported service providers.

We perceived a difficulty in being able to align the needs of service providers (many of whom understood the real complexities of risks being generated by the local ecosystems they were providing services to) and the supporting tool providers (who were oriented more towards developing a single unified model of tool support). A preliminary report identified this imbalance, and described the extent of this needed change in approach and its practical implications. A deeper analysis of the organizational structures of responsibility and accountability and their associated economics was a topic for a subsequent cycle, since an analysis of the economics would necessarily be the main driver of any beneficial change in approach.

The client agency accepted that the environment the service providers faced was one in which demand was asymmetric, and given the scale of the conceptual shift that acceptance implied, this outcome was appropriate. However, in this case the client agency determined that their role in the overall situation was one of more limited influence than was appropriate to effecting the scope of changes needed The study was concluded at this point. So in this case, the framing process was as far as the client agency went with the SoS Navigator approach.

Table 9:   Summary of Addressing Massive Context Shift Engagement (Nine-Month Period)

	Scheduled/Executed Activities	**SoS Navigator Tools and Techniques**
SoS Navigator Framing Process		
Understand supply and demand basic relationships	- Initial analysis establishing user/developer gaps and extent of tools and technologies fragmentation - Interviews and workshops establishing extent of data fusion challenges in forming mitigation strategies. Organization and technical structure and process gaps identified	Asset Analysis, Congruence Analysis, Center Push/Edge Pull Analysis, Scenario Analysis

5   Plans for Future Work

SoS Navigator processes, tools, models, and techniques evolve as we work with client organizations facing different systems-of-systems challenges. We expect our work to take us in these directions:

- *evolving and clarifying SoS Navigator processes, tools, and techniques, so that we can transition them widely*

  Some SoS Navigator processes, tools, and techniques have been heavily used in certain contexts (e.g., healthcare or military) and require evolution into more general forms. Others rely on specialist language that makes them less accessible to the community to which ISIS responds. A particular area of interest is exploiting the richness of the PAN technology, a set of techniques and modeling approaches that can account for demand-driven interoperability relationships between aspects of an enterprise, and similarly robust tools.

- *exploring and refining the concepts that underpin the SoS Navigator approach, so that we can better understand the variety of demands to which it can effectively respond*

  SoS Navigator concepts derive from a wide variety of intellectual disciplines and influences. Some of the concepts described in this technical note (see Section 2) deserve further exploration and refinement to ensure that we understand the boundaries of their utility.

In pursuing both of these paths, we will derive benefit from a combination of collaborative piloting and reflective synthesis. Through piloting, we will gain more real-world information about the usefulness, effectiveness, and adaptability of tools, techniques, and models; we will also gain insight into nuances about our processes. Between engagements, we will codify what we have observed and learned, modifying our SoS Navigator approach as needed, as well as identifying new techniques that are needed. The pace of progress toward a state where the approach can be readily transitioned will be determined in large part by the opportunities we find for balancing these two important activities.

6 Conclusion

Organizations in government and industry are moving inexorably toward greater development, evolution, and use of complex systems of systems. The SoS Navigator approach can provide technical and organizational leaders with insight into the characteristics and behavior of the systems of systems they rely upon.

In this technical note, we have discussed several related concepts of the SoS Navigator approach that are fundamental to comprehending these systems.

- The SoS enterprise includes all the socio-technical elements that are on the provider side of the purchaser-provider boundary in complex systems of systems.
- Satisfying an asymmetric demand is an ongoing process of continually changing responses answering dynamically evolving, unpredictable demands.
- The gap between demand and supply is evident in the disconnection between systems suppliers and the users who daily make decisions about how they will perform their jobs on the demand-side.
- There are dynamically changing demand situations that drive required agility.
- It is necessary to cross the boundaries of the governance structures of multiple enterprises to respond appropriately to asymmetric demand.
- There must be some balancing force in place that maintains a dynamic form of governance throughout the SoS enterprise.
- Flexibility and adaptability are needed to dynamically orchestrate and synchronize solutions in response to edge-driven demands.

The SoS Navigator approach builds on those concepts with processes to frame the context of client organizations in relationship to the notion of the SoS enterprise and take steps to adopt new business models as needed. Each process involves several diagnostic and analytic techniques that allow us to expand our understanding of supply and demand and their relationship to each other.

We have begun to codify and generalize techniques to support SoS Navigator, after using them in consulting contexts such as the ones profiled in Section 4. The version of SoS Navigator described in this technical note focuses on the tools and techniques that support moving toward a systems-of-systems context of distributed collaboration responding to asymmetric demand. Future technical notes will expand the detail, scope, and use of the SoS Navigator approach.

Appendix   Evolution between SoS Navigator 1.0 and 2.0

The purpose and goals for SoS Navigator have remained the same as SoS Navigator version 1.0 has evolved into version 2.0. The conceptual elements have also remained constant, although terminology has changed. SoS Navigator version 1.0 established the need and a conceptual skeleton. SoS Navigator version 2.0 now adds various organs and connective tissue.

The stated purpose for SoS Navigator 1.0 was to help organizations chart a path through a system-of-systems environment by providing tools and techniques to characterize organizational, technical, and operational enablers and barriers to success, identify improvement strategies, and pilot and institutionalize these strategies. SoS Navigator version 2.0 continues these goals with one key refinement. SoS Navigator version 2.0 focuses on the more complex systems-of-systems situations where there is a need for distributed collaboration in an environment of highly variable demand.

SoS Navigator version1.0 was composed of three key elements:

1. a conceptual *framework* to codify core paradigms, concepts, and principles
2. processes, tools, and techniques to *chart* where a systems-of-systems environment is and where it needs to go
3. processes, tools, and techniques to *improve* organizations within a systems-of-systems context

In addition to the three basic elements, the SoS Navigator version 1.0 concept was based on creating an internal consistency between the framework providing the core foundation and the processes, tools, and techniques for charting and improving. The initial set of concepts, processes, tools, and techniques was used in several customer engagements to validate the general approach.

SoS Navigator 2.0 introduces significant improvements to the implementation of the original key elements, while retaining the three key elements and their internal consistency. SoS Navigator 2.0 retains the conceptual framework and reconstitutes the *chart* and *improve* elements into a framing process and learning/transformation cycle, as follows:

- the *framing* process, with associated diagnostic techniques, allows understanding and characterization of the relevant participants and determines whether the SoS enterprise needs to respond to highly variable demand situations
- the continuous *learning/transformation cycle*, with additional analytical and organizational change techniques, allows transformation of the business model of the SoS enterprise and supports associated technical and organizational changes

SoS Navigator version 2.0 provides a richer set of fundamental concepts and principles. The new diagnostic and analytical techniques which support the framing process and learning/transformation cycle provide a deeper understanding of the elements and their relationships in an SoS enterprise. The SoS Navigator version 2.0 fundamental concepts, processes, and techniques have been used on a broad spectrum of SoS enterprises, providing significant non-intuitive insights (some of which are summarized in this report).

References

URLs are valid as of the publication date of this document.

[Anderson 2006]
Anderson, William, Boxer, Philip, & Brownsword, Lisa. *An Examination of a Structural Modeling Risk Probe Technique* (CMU/SEI-2006-SR-017). Software Engineering Institute, Carnegie Mellon University, 2006.
http://www.sei.cmu.edu/publications/documents/06.reports/06sr017.html

[Ashby 1963]
Ashby, W. R. *Introduction to Cybernetics*. John Wiley, 1963.

[Beaudouin-Lafon 1999]
Beaudouin-Lafon, Michel, ed. *Computer Supported Co-operative Work (Trends in Software, 7)*. John Wiley & Sons, 1999 (ISBN 0-471-96736-X).

[Beer 1959]
Beer, A. S. *Cybernetics and Management*. English Universities Press, 1959.

[Boxer 2008]
Boxer, Philip, Morris, Ed, Anderson, William, & Cohen, Bernard. "Systems-of-Systems Engineering and the Pragmatics of Demand," 341–347. 2008 IEEE International Systems Conference. Montréal, Québec, Canada, April 7–10, 2008. IEEE, 2008.

[Boxer 2007a]
Boxer, Philip. *The hole-in-the-middle*. http://www.asymmetricdesign.com/archives/79 (2007)

[Boxer 2007b]
Boxer, Philip. *Strategy-at-the-edge*. http://www.asymmetricdesign.com/archives/82 (2007)

[Boxer 2006a]
Boxer, Philip. *Finding the edge*. http://www.asymmetricdesign.com/archives/56 (2006)

[Boxer 2006b]
Boxer, Philip. *The double challenge*. http://www.asymmetricdesign.com/archives/26 (2006)

[Boxer 2006c]
Boxer, Philip. *East-West Dominance*. http://www.asymmetricdesign.com/archives/32 (2006)

[Boxer 2006d]
Boxer, Philip. *Meeting the Challenge of Health Care Reform*
http://www.asymmetricdesign.com/archives/72 (2006).

[Boxer 2006e]
Boxer, Philip. *Type III Agility in Organisations.*
http://www.asymmetricdesign.com/archives/101 (2006)

[Boxer 2005]
Boxer, Philip. *Asymmetric Demand*. http://www.asymmetricdesign.com/archives/3 (2005)

[Brewer 2006]
Brewer, Gene A., Neubauer, Bruce J., & Geiselhart, Karin. "Designing and Implementing E-Government Systems: Critical Implications for Public Administration and Democracy." *Administration & Society 38*, 4 (2006): 472.
http://aas.sagepub.com/cgi/content/abstract/38/4/472

[Brownsword 2006]
Brownsword, Lisa, Fisher, David, Morris, Ed, Smith, James, & Kirwan, Patrick. *System-of-Systems Navigator: An Approach for Managing System-of-Systems Interoperability* (CMU/SEI-2006-TN-019). Software Engineering Institute, Carnegie Mellon University, 2006. http://www.sei.cmu.edu/publications/documents/06.reports/06tn019.html

[BSI 2007]
Balanced Scorecard Institute. *Definitions of General Management Terms*.
http://www.balancedscorecard.org/Definitions/tabid/145/Default.aspx (2007)

[Emery 1965]
Emery, F. E. & Trist, E. "The Causal Texture of Organizational Environments." *Human Relations 18* (1965): 21−32.

[Fisher 2007]
Fisher, David A., Meyers, B. Craig, & Place, Pat. *Conditions for Achieving Network-Centric Operations in Systems of Systems* (CMU/SEI-2007-TN-003). Software Engineering Institute, Carnegie Mellon University, 2007.
http://www.sei.cmu.edu/publications/documents/07.reports/07tn003.html

[Forrester 2006]
Forrester, E., ed. *A Process Research Framework*. Software Engineering Institute, Carnegie Mellon University, 2006. http://www.sei.cmu.edu/publications/books/process/iprc.html

[Hirschhorn 1984]
Hirschhorn, Larry. *Beyond Mechanization: Work and Technology in a Postindustrial Age*.
MIT Press, 1984.

[Kolb 1984]
Kolb, David A. *Experiential Learning: Experience as the Source of Learning and Development*. Prentice-Hall Inc, 1984.

[Maturana and Varela 1980]
Maturana, H. R. & Varela, F. J. *Autopoiesis and Cognition: The Realization of the Living, vol. 42*. D. Reidel, 1980.

[Miller 2001]

Miller, Ann. "Trends in software systems." *IEEE Potentials*, December/January (2001): 11−13. http://ieeexplore.ieee.org/iel5/45/19268/00890083.pdf

[Morris 2006]

Morris, Ed, Place, Pat, & Smith, Dennis. *System-of-Systems Governance: New Patterns of Thought* (CMU/SEI-2006-TN-036, ADA467577). Software Engineering Institute, Carnegie Mellon University, 2006.
http://www.sei.cmu.edu/publications/documents/06.reports/06tn036.html

[Normann 2001]

Normann, Richard. *Reframing Business. When the Map Changes the Landscape*. John Wiley & Sons, 2001.

[OASIS 2006]

Organization for the Advancement of Structured Information Standards (OASIS). *Reference Model for Service Oriented Architecture 1.0, Committee Specification 1, 2 August 2006*.
http://www.oasis-open.org/committees/download.php/19679/soa-rm-cs.pdf

[Oracle 2007]

Oracle's FAQs. *Category: E*. http://orafaq.com/wiki/Category:E (2007).

[Rosen 1991]

Rosen, Robert. *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life*, Columbia University Press, 1991.

[Singh 2007]

Singh, Inder M. "Linux Trends in Embedded Systems." *Embedded Computing Design*.
http://www.embedded-computing.com/articles/singh/ (2007)

[Smith 2006]

Smith, James D. II & Phillips, D. Mike. *Interoperable Acquisition for Systems of Systems: The Challenges* (CMU/SEI-2006-TN-034, ADA461385). Software Engineering Institute, Carnegie Mellon University, 2006.

[Trist and Murray 1993]

Trist, E. & Murray, H., eds. The *Social Engagement of Social Science, Volume II*. Free Association, 1993.

[Trist and Murray 1990]

Trist, E. & Murray, H., eds. *The Social Engagement of Social Science, Volume 1*. Free Association, 1990.

[USCB 2002]

United States Census Bureau. *Glossary of Terms for the Economic Census: Enterprise*.
bhs.econ.census.gov/econhelp/glossary/#E (2002)

[USIM 2001]
U. S. Institute of Medicine. *Crossing the Quality Chasm, A New Health System for the Twenty-First Century*. National Academy Press, 2001.

[Wikimedia 2008]
Wikimedia Foundation. *Celestial Navigation*.
http://en.wikipedia.org/wiki/Celestial_navigation (2008).

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE June 2008	3. REPORT TYPE AND DATES COVERED Final
4. TITLE AND SUBTITLE SoS Navigator 2.0: A Context-Based Engineering Approach to System-of-Systems Challenges		5. FUNDING NUMBERS FA8721-05-C-0003
6. AUTHOR(S) The SEI SoS Navigator Team		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Software Engineering Institute Carnegie Mellon University Pittsburgh, PA 15213		8. PERFORMING ORGANIZATION REPORT NUMBER CMU/SEI-2008-TN-001
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) HQ ESC/XPK 5 Eglin Street Hanscom AFB, MA 01731-2116		10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES		
12A DISTRIBUTION/AVAILABILITY STATEMENT Unclassified/Unlimited, DTIC, NTIS		12B DISTRIBUTION CODE

13. ABSTRACT (MAXIMUM 200 WORDS)

Organizations struggle with many problems in complex systems of systems for which solutions are not codified or even conceived, such as a mutual understanding of "common" terms and concepts across participating enterprises and the lack of a global view by any single system-of-systems participant. System and software purchasers and suppliers need a different set of approaches and techniques than are typically in use today to satisfy user demands that reflect turbulent operational environments. Beyond purchasers and engineers, all participants in a complex, systems-of-systems environment need a different set of perspectives and expectations about user demands than those typical in product-centered engineering. The SoS Navigator approach provides leaders participating in complex systems of systems with (1) novel insights into critical aspects of the demand and supply sides of their situation and (2) criteria on which to decide whether their systems-of-systems context requires the adoption and sustainment of a different business model than ones that are typical today. This technical note introduces the fundamental concepts, processes, and techniques of the evolving SoS Navigator approach. It also summarizes case studies that illustrate the use of SoS Navigator processes and tools in healthcare, military, and civilian government systems-of-systems contexts.

14. SUBJECT TERMS Systems of systems, distributed collaboration, governance, SoS Navigator		15. NUMBER OF PAGES 48
16. PRICE CODE		

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL